

A GROUND-TRUTH DATABASE FOR CENTRAL CHINA

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ABSTRACT

We have constructed a ground-truth database consisting of phase-picks data and other geological and geophysical information in Sichuan and Yunnan Provinces in central China. The database includes 1,600 regional seismic events with over 40,000 phase picks recorded by the regional seismic network in central China from 1985 to 1994. The distribution of the seismic events covers the area 97°E to 108°E and 20°N to 40°N, with magnitudes $ML = 0.3-6.9$ and a maximum depth of 41 km. The data listing in the database is raw data information and contains a comprehensive listing of all phases that were detected. The listed information of the earthquakes includes origin time, epicenter location, magnitude, and focal depth. Major phase picks, such as Pn, Pg, Sg, were reported. Quality control is performed on the raw data, and unreliable picks are discarded. The data are compiled and stored in CSS format. The flat file tables include the origin, arrival, association, and site tables. As part of the effort to construct a comprehensive ground-truth database of central China, other geological and geophysical information such as the seismogenic structure in central China, is also included.

This data set forms the basis of an initial input to a ground-truth database for central China and has been delivered for incorporation into the Knowledge Base developed by the Department of Energy. Analysis of the data has been performed to yield a preliminary velocity model in central China. We performed a three-dimensional (3-D) tomographic inversion in central China by using the phase-picks data in the database. Altogether, 372 events are selected with over 5,900 P-phase arrivals. A five-layer 1-D starting model is chosen according to previous studies in the region. The studied region is divided into 16 by 16 blocks with a resolution of 0.5 degree. A 63% reduction in data variance is achieved after the fifth iteration of the joint inversion of crustal structure with relocation of the events. The results show correlation between the topography and the crustal velocity structure. The resultant crustal model also improves the clustering pattern of the seismic events in the region.

Key Words: ground-truth database, phase arrival time data, tomographic inversion, relocation, China

OBJECTIVE

The current research focuses on collection, processing, and analysis of historical seismic data for central China and assembly of these data in the form of a ground-truth database. As a Phase I feasibility study, we have collected representative ground-truth information for a preliminary analysis of travel times and crustal velocity structure. Seismic wave travel-time data in central China are collected and processed. A preliminary 3-D regional crustal structure in central China is obtained through tomographic inversion. We have also collected geological and geophysical maps of central China. A more extensive data collection and analysis leading to a comprehensive ground-truth database will be conducted in Phase 2.

RESEARCH ACCOMPLISHED

GEOLOGICAL AND GEOPHYSICAL SETTINGS

The central China region is located in a transitional zone between two different continental crusts of eastern and western China. The region is composed of three major tectonic blocks: the Garze block, central

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Sichuan block and Aba block. Under regional tectonic movement, these blocks have been subject to strong horizontal compression. The collision and subduction of the Indian and Philippine Sea plates towards the Eurasian plate cause highly active seismicity in central China. The Xianshuihe, Minjiang, Maowen-Tianquan, Anninghe and Zemu faults along the block boundaries are driven by the tectonic movement and produce frequent and strong earthquakes.

The area of Sichuan west to Yaan consists of high mountains and platforms at the edge of the Tibetan Plateau. In the western Sichuan and eastern Tibet area, the topography is very complicated, with outcrop of shale, limestone, igneous rock, and other rocks. East to Yaan are the plain and hilly areas with elevations under 800 m. The Bangonghu-Nujiang, Jinshajiang and Xianshuihe-Xiaojiang fault zones are the major bent structures in central China surrounding the Indian Plate. Geologists believe that these fault zones consist of major faults that cut through the mantle and are the boundaries of the tectonic plates. From the age and range of the rocks in the fault zone, it is obvious that the bent zones become younger from the northeast to the southwest. It is hypothesized that during the long history of geological development, there were many collisions or under-thrusts between the tectonic plates in the southwestern China region. The bent boundaries between the tectonic plates retreated towards the southwest with a certain distance after each collision, and finally reached the present location in the Yaluzangbujiang-Yiluowadijiang zone. There is still active movement in the region, which causes the geological and geophysical activities in the bent zones.

Major geological structures in the central China region include the Sichuan platform syncline and the Longmenshan platform fold zone in the Yangtze Platform, the Keke xilibayankela geosyncline fold zone, the Batangimo geosyncline fold zone and the Kelakunluntanggula geosyncline fold zone in the Kunlunshanjia fold system, the Gaizenaqu geosyncline fold zone in the Zangzhongnan platform and the Nianqintanggulagaoligong fault uplift zone (Ma, 1989).

SEISMICITY IN CENTRAL CHINA

Seismicity in central China is distributed along orogenic belts. There are the Xianshuihe earthquake belt, Litang earthquake zone and Batang earthquake zone in the region.

- 1) Xianshuihe earthquake belt: Since 1725, there have occurred 66 earthquakes with $M > 4.75$, among which there were 9 earthquakes with $M > 7$, 10 earthquakes with $6.1 < M < 6.9$, 26 earthquakes with $5.1 < M < 6.0$ and 21 earthquakes with $4.75 < M < 5$. From the August 1, 1725, Kongding $M = 7$ earthquake to February 6, 1973, $M = 7.6$ Luhuo earthquake, there were 9 earthquakes with $M > 7$ in the region. The Xianshuihe earthquake belt is an active earthquake zone with strong and frequent earthquakes. The focal depths are mostly within 10-20 km. The focal mechanisms show that the stress field has a SW-NE trend and the earthquakes are mainly strike-slip events.
- 2) Litang earthquake zone: Since the August 24, 1930, $M = 5.5$ Litang earthquake, there have been 9 earthquakes in the zone, among which there were 1 earthquake with $M > 7$ (May 25, 1948 $M = 7.3$ Litang earthquake), 5 earthquakes with $5.1 < M < 5.9$ and 3 earthquakes with $M < 5$.
- 3) Batang earthquake zone: Since the 1722 $M = 6$ Batang earthquake, there have been 10 earthquakes with $M > 4.7$, among which there were 1 earthquake with $M > 7$ (April 11, 1870 $M = 7.5$ Batang earthquake), 4 earthquakes with $6 < M < 6.9$, and 5 earthquakes with $5 < M < 5.9$. There were 5 earthquakes with $M > 5.5$ in 1989.

PREVIOUS STUDIES ON CRUSTAL STRUCTURE IN CENTRAL CHINA

Regional phases of Pn, Sn, P, and S in central China were investigated by using the broadband digital seismic recordings (Ding et al., 1993) in the Eastern Tibet and Western Sichuan region. Velocities of Pn, Sn, P, S were determined from them. Average velocities of P and S are 5.6-6.0 km/s and 3.3 km/s, respectively, and those of Pn and Sn are 8.17 km/s and 4.6 km/s, respectively. The normal velocities of Pn and Sn in the Tibetan Plateau provide important evidence that both the thermal condition and material in the uppermost mantle of the Tibetan Plateau do not differ very much from those in other normal continents.

The reported velocity of Pn in the Tibetan Plateau varies from 8.0 km/s to 8.4 km/s or higher. Due to the difficulty of picking Sn phase from the seismogram, velocity of Sn in Tibetan Plateau has rarely been reported. Chen and Molnar (1981) and Barazangi and Ni (1982) obtained a value of 4.7 km/s for the velocity of Sn. Zhao and Zeng (1993) obtained another value of 4.55 km/s for Sn velocity. However, most of the previous results were obtained by using Tibetan earthquakes recorded by seismic stations in the neighboring areas. Seismic rays usually travel through a significant portion of non-Tibetan path. Also, a large range of epicentral distance (up to 18°) had been used in those studies.

From Zhao and Xie (1993), an abrupt change of crustal thickness from 79 km in Qiangtang block to 64 km in Songpan block is observed. It agrees very well with the results from teleseismic waveform inversion mentioned above. Less certain is the greater Pn velocity in the uppermost mantle of a narrow belt from Amdo to Golmud (Zhao and Xie, 1993).

GROUND-TRUTH DATABASE OF PHASE PICKS DATA IN CENTRAL CHINA

We have collected seismic data in central China from 1985 to 1994. A database has been constructed with 1,600 seismic events in central China that were recorded by the regional seismic network with over 160 seismic stations operated mainly in Sichuan and Yunnan provinces (Fig. 1). A comprehensive listing of over 40,000 seismic phase arrival time data in Central China are compiled in the database.

The distribution of the seismic events covers the area 97°E to 108°E and 20°N to 40°N, with magnitudes $M_L = 0.3-6.9$ and a maximum depth of 41 km. The data listing in the database is raw data information and contains a comprehensive listing of all phases that were detected. The listed information of the earthquakes includes origin time, epicenter location, magnitude, and focal depth. Major phase picks, such as Pn, Pg, Sg, were reported. The data are compiled and stored in CSS format. The plain text tables include the origin, arrival, association and site tables.

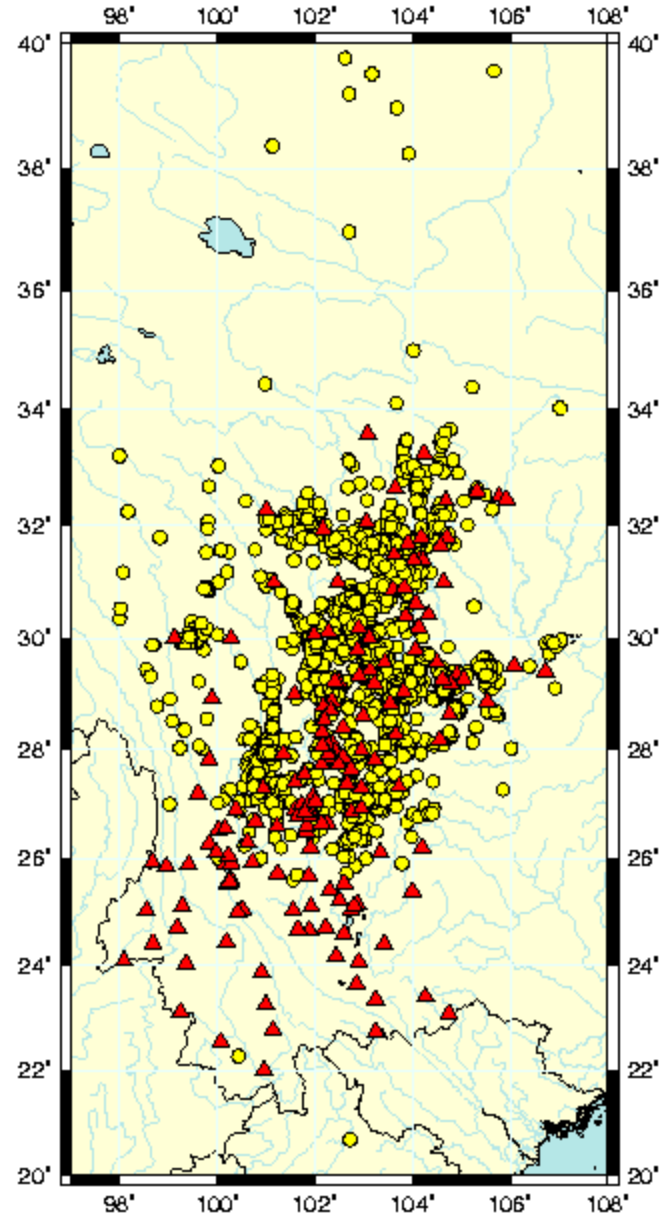


Fig. 1 Location of the seismic events in the central China ground-truth database. The circles denote the seismic events, and the triangles indicate the seismic stations.

Quality control is performed on the raw data. The phase arrival times are verified and validated independently. The arrival times are plotted against the epicentral distances and those that are deviated significantly from the average travel-time curves are regarded as unreliable picks and eliminated from the database. To illustrate the quality of the seismic data after quality control, the phase arrival times are shown in Fig. 2. Overall, the fluctuations in the travel-time curves are limited, which ensures the quality of phase picks data.

This data set forms the basis of an initial input to a ground-truth database for central China and has been delivered for incorporation into the Knowledge Base developed by the Department of Energy. Analysis of the data has been performed to yield preliminary velocity model and event relocation. These data may also be correlated with data obtained from the Chinese Digital Seismic Network (CDSN) to establish ground-truth database information for the region.

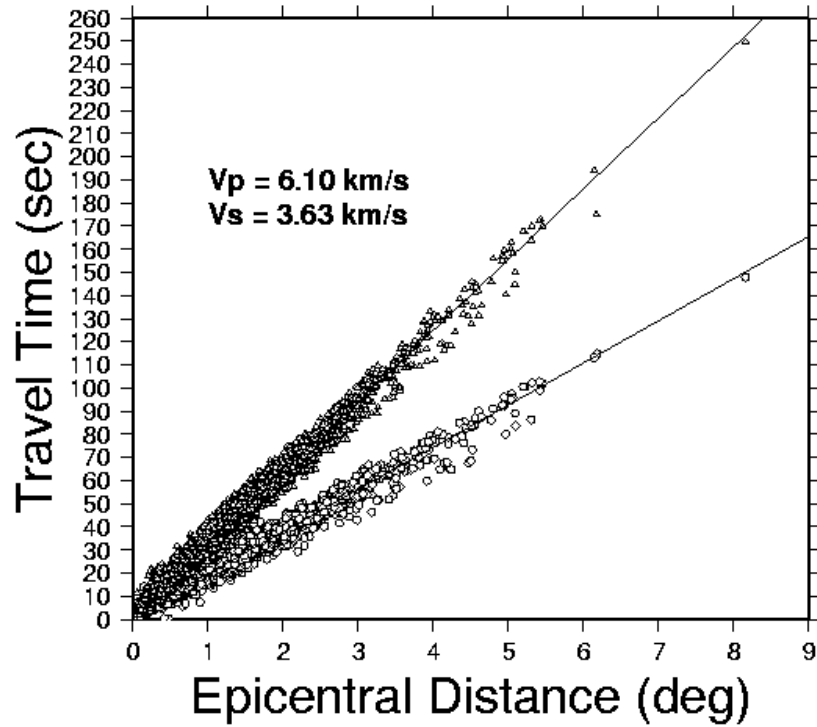


Fig. 2 Pg (circles) and Lg (triangles) travel times against epicentral distance. The P and Lg wave velocities are 6.1 and 3.63 km/sec, respectively.

3-D TOMOGRAPHIC INVERSION

The precise location of seismic events depends on the correctness of the earth model used in the location procedure, especially when dealing with events with small magnitudes that are only recorded in local or regional distances. Lateral heterogeneity can certainly affect the precision of the location of the events. To improve the confidence of the location of seismic events, a three-dimensional regional earth model of high resolution is desirable. The seismic phase picks data collected in central China are used to perform a 3-D tomographic inversion of the regional crustal structure.

We adopt the 3-D tomographic inversion method by Roecker (1987, 1993) and choose 372 seismic events from the compiled database for the 3-D tomographic inversion. The criterion for event selection is based on the density of event distribution in the region. In the central area, where the seismic events prevail, only those that are recorded by at least 20 stations are selected, but in the perimeter area, where the event density is less populated, the criterion is reduced to 5 stations to ensure sufficient coverage of the region. The event location, seismic station location and ray path projection are shown in Fig. 3. The spatial distribution of the events covers central China in the area 97°E - 108°E , 24°N - 35°N with focal depths up to 41 km.

Among the earthquakes adopted for the inversion, large portions of them are located in the central area of the inversion region. Lattice of varying grid sizes is employed to reflect the density of seismic ray coverage where the grid spacing is 0.5 degree in the central area and 2 degrees in the perimeter. The crust in the studied area is divided into 5 layers and each layer is partitioned into 16×16 cells (Fig.3).

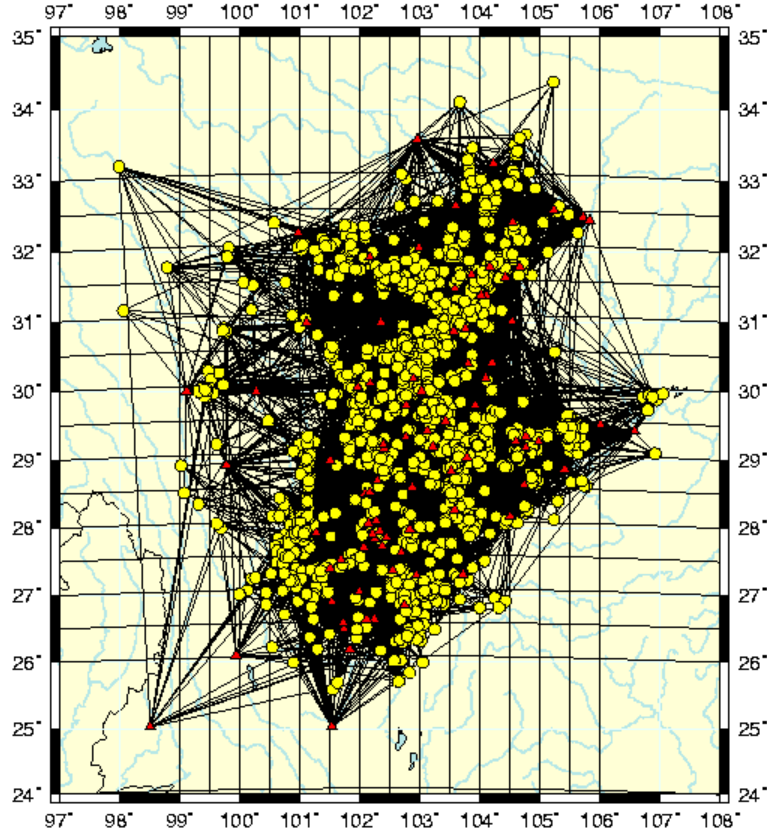


Fig. 3. Ray path projection for the seismic events adopted for the tomographic inversion. The circles denote the seismic events, and the triangles represent the seismic stations. Lattice of different grid sizes is utilized to reflect the density of ray path coverage.

A 1-D starting model of the velocity structure of central China is set up according to the previous seismic profiling in the region (Lin, *et al.*, 1993; Wang, *et al.*, 1994). The crust in the region is divided into 5 layers (Table 1).

Table 1 Starting model of crustal structure in central China

| Layer | Depth (km) | P-wave velocity (km/s) |
|-------|------------|------------------------|
| 1 | 4.0 | 4.50 |
| 2 | 14.0 | 6.00 |
| 3 | 22.0 | 6.25 |
| 4 | 33.0 | 6.40 |
| 5 | 45.0 | 6.70 |

We perform the tomographic inversion by iteration. In each iteration, the 3-d velocity structure is obtained by inverting the P-wave arrival times. Over 5,900 P-phase arrival times are used in the inversion. After the inversion of the velocity structure, all the events are relocated based on the new 3-D velocity model in a separate step. The new locations of the events are then adopted for the next iteration of tomographic inversion. The iteration is terminated when the improvement of the velocity model is negligible.

The resulting P-wave velocity after the 5th iteration of the tomographic inversion is shown in Fig.4 (a)-(e). Both lateral heterogeneity and vertical variation are observed through the results. The trend of the variation of P-wave velocity in the first layer is found to correlate with the topography and tectonic settings in the region. In the eastern portion of the studied area, the velocity anomaly trends in NNE direction, which is consistent with the geological structures and earthquake faulting in the region. The velocity anomaly generally trends in N-S direction in the central portion and NW direction in the western portion. The same trends are observed in the 2nd layer, but become less evident as it goes further down.

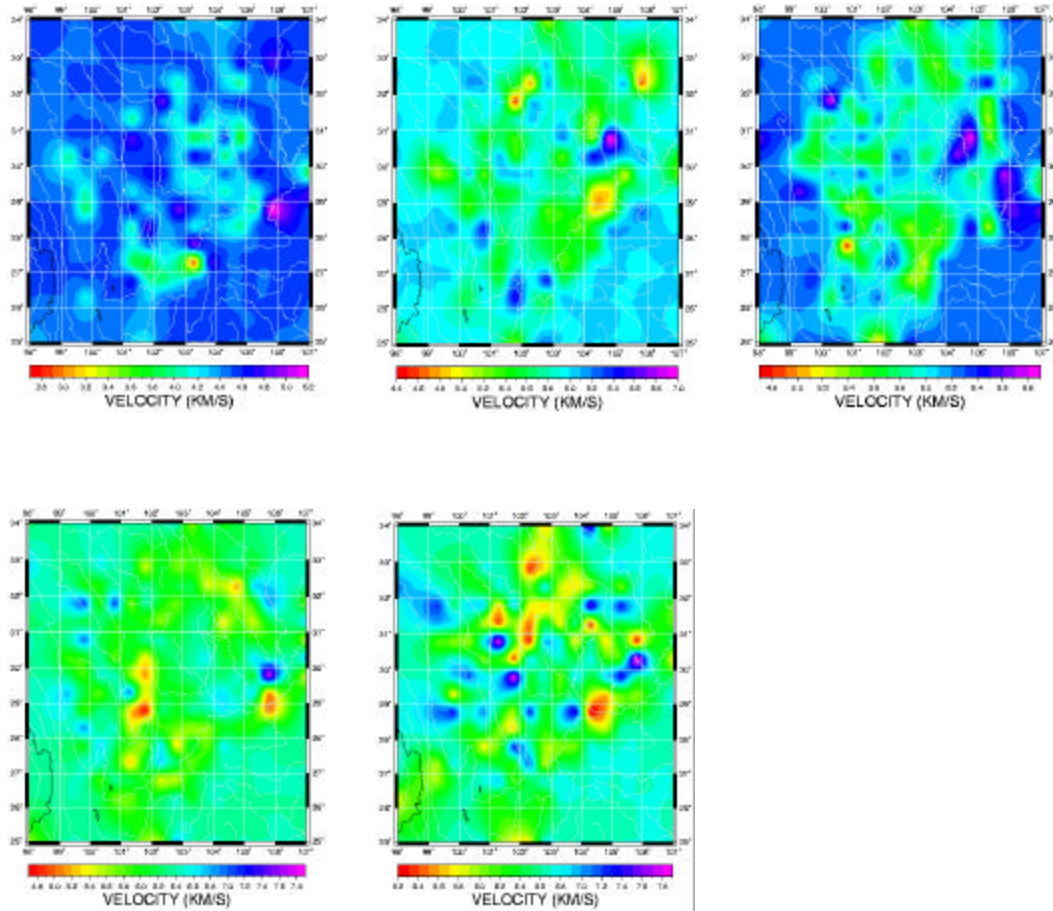
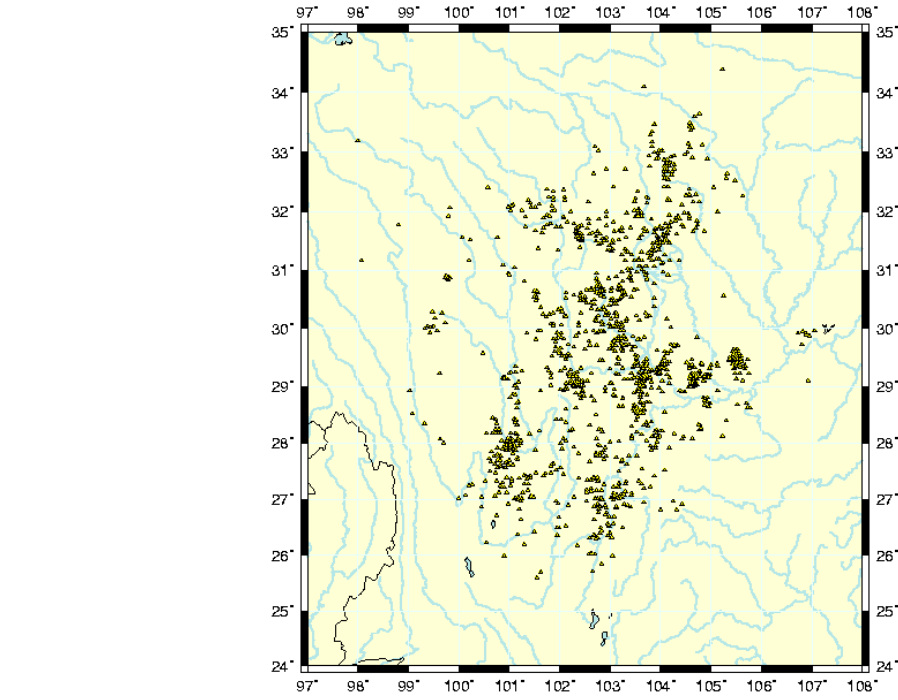


Fig. 4 P-wave velocity after the 5th iteration of tomographic inversion at layers at 4, 14, 22, 33, and 45 km.

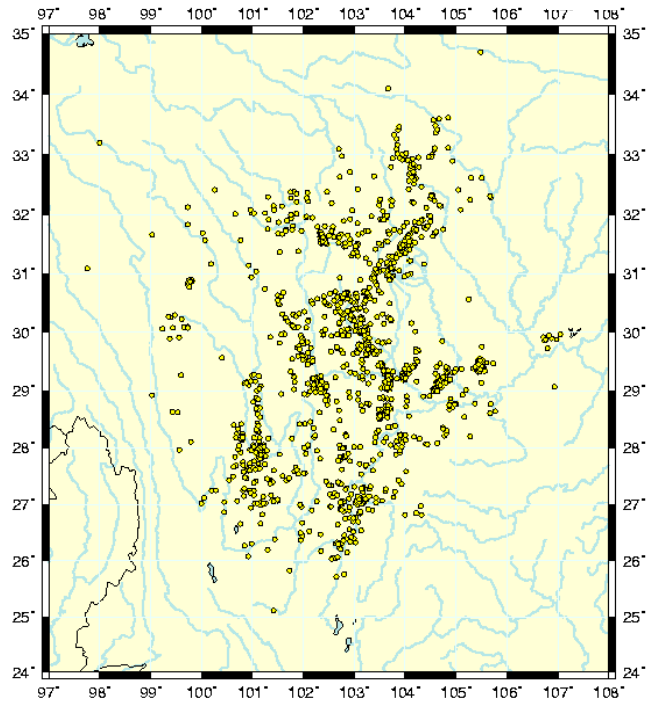
RE-LOCATION OF SEISMIC EVENTS

During the tomographic inversion of the 3-D crustal velocity structure in central China, a 63% reduction of the variance of the travel-time data is achieved after the 5th iteration. The standard error in the re-location of the events is usually less than 2 km in epicenter and less than 5 km in depth. Utilizing the 3-D crustal structure obtained from the inversion, we relocate the seismic events that are recorded by at least 5 stations in the studied region. It is found that the relocated epicenters show improvements in the clustering pattern over the original locations (Fig. 5a, b).

The earthquakes are more concentrated and have a better correlation with the earthquake faults in the region. The result demonstrates the necessity of regional crustal structure of high resolution in relocation of seismic events.



(a)



(b)

Fig. 5 Seismic event epicenter distribution before (a) and after (b) the relocation.

CONCLUSIONS AND RECOMMENDATIONS

This research is aimed at obtaining a database of historical seismological, geophysical, and geological data for central China. By obtaining the local seismic data, better models of the regional crustal structure can be made. We have collected the historical earthquake data in central China recorded by the local and regional seismic networks and constructed a database of phase arrival times. The database consists of 1,600 seismic events from 1985 to 1994 with over 40,000 entries of seismic phase arrival times. The seismic events occurred in central China and the vicinity within an area about $20^{\circ} \times 11^{\circ}$. The events were recorded by the local and regional seismic networks operated by the provincial seismic bureaus in central China with over 160 seismic stations. The phase arrival time data are verified and validated independently. Unreliable phase picks that are deviated significantly from the average travel-time curves are discarded. The data are compiled in CSS format. The historical earthquake data provide a unique seismic database for further refinement of the regional crustal structure.

We performed a 3-D tomographic inversion of the crustal structure in central China utilizing the obtained seismic data. Previous research on the crustal structure in central China is analyzed and summarized to set up a 1-D starting model. A total of 372 events and over 5,900 P-phase arrival times are adopted to carry out a tomographic inversion of the crustal velocity structure in the region. The results reveal complex lateral heterogeneity of the crustal structure in central China. We find correlation among the velocity structure, topography and tectonic structures in the region. The resultant 3-D crustal structure improves the clustering pattern of the seismic events.

Recent seismic data from the new digital seismic networks in central China are desirable to enhance the ground-truth database and improve the study of the crustal structure in the region. It is also an interesting research topic to perform the similar study in other areas in China where the high-resolution crustal structure is not well understood yet.

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